PILOT

Policy and Innovation in Low-Tech

Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges

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ABSTRACT

This paper addresses a central problem for economic analysis and public policy in Europe. Should Europe focus on so-called high-technology or science-based industries in attempting to solve growth and employment problems? Or should it look to the growth prospects within the industries on which the European economy is actually based: low-technology and medium-technology industries (which we call 'LMT industries') in manufacturing and services? These questions are the focus of a European Commission research project called PILOT – 'Policy and Innovation in Low-Tech' (see www.pilot-project.org). This paper is a first output from the project – it addresses key issues in understanding LMT industries, mainly in terms of knowledge intensity and use.

There are many who argue that high-technology industries are the bearers of the new knowledge economy. They argue that Europe should focus on knowledge intensive activities in such frontier areas as ICT, biotechnology and professional services. A related claim is that mature, traditional or LMT industries are likely to move to less developed countries.

We claim that these perspectives are seriously mistaken. Taken together, LMT activities account for somewhere in the region of 97% of all economic activity in Europe. All European economies are trade-specialized in LMT products. All LMT industries are innovative – they generate significant proportions of their sales from new and technological changed products. Many LMT industries and products are surviving and growing on the basis of technological upgrading, high-grade design skills and the intensive application of knowledge to innovation. They have unique forms of industrial organisation and knowledge creation, complex links to science and technology knowledge infrastructures, and important regional dimensions.

Here we focuses on the creation and use of knowledge in LMT industries. We claim that in the future the European economy, especially in the context of enlargement, will continue to rest on LMT activities. This implies that growth, competitiveness, cohesion and employment in Europe will depend on the performance of LMT industries. At the present time, the knowledge-creation problems faced by such sectors are neglected in policy arenas – but this will become a major challenge for EU innovation, technology and research policy.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Technology Management	
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Contents

Summary

In the mid-1980s, the OECD invented an economic classification that has had a spectacular career - the concept of high-technology, medium-technology and low-technology industries. This taxonomy was based primarily on the R&D intensity of industries, meaning the ratio of R&D expenditure to output. Industries with an R&D/Turnover ratio of more than four percent were classified as high-tech. Those between one and four percent were medium-tech, and those less than one percent were low-tech. This schema has become widely used in business, in policy discussions and in economic analysis. It links with other classifications that seek to differentiate 'science-based' or 'knowledge intensive' industries from more prosaic activities.

This paper addresses a central problem for economic analysis and public policy in Europe. Should Europe focus on so-called high-technology or science-based industries in attempting to solve growth and employment problems? Or should it look to the growth prospects within the industries on which the European economy is actually based: low-technology and medium-technology industries (which we call 'LMT industries') in manufacturing and services? These questions are the focus of a European Commission research project called PILOT – 'Policy and Innovation in Low-Tech' (see www.pilot-project.org). This paper is a first output from the project – it addresses key issues in understanding LMT industries, mainly in terms of knowledge intensity and use.

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Introduction

In recent meetings in Lisbon and Barcelona, EU Heads of Government adopted and then reaffirmed the objective of making the EU the world's most competitive knowledge-based economy by 2010. How this objective might be reached has been debated since then, focussing especially on an important target indicator selected to reflect the objective, namely that the EU should achieve an R&D/GDP ratio of three percent.

Both the objective and the indicator raise problems of interpretation. How should we understand the knowledge economy, and how can its performance be measured? Is R&D the only or best indicator of knowledge creation, and if not, what are the implications for the innovation potential of European industry? This paper argues that such questions have often attracted simplistic answers – we suggest that the knowledge economy has been too often identified with high-tech, high-R&D industries. These industries are small and unrepresentative of the European economic structure. Concentrating on them obscures important processes of knowledge creation and innovation in the modern European economies. In this paper we argue that low and medium technology (LMT) industries are of great and continuing economic importance in advanced economies. We focus on how they create and use knowledge, arguing that LMT industries intensively create and deploy many forms of production-relevant knowledge, including basic science results, and that they are central to the knowledge economy.

What is the background to the policy obsession with high tech industries? In large part it reflects the idea that ongoing societal change in modern societies can be characterised as an emerging "Knowledge Society" (cf. Drucker, 1994; Stehr, 1994; Willke, 1998; David and Foray, 2003) or "Learning Economy" (cf. Lundvall and Borrás, 1997). These writers and others share the idea that modern organisations and societies are undergoing a fundamental change process, resting on an enhanced significance of knowledge as a productive force and asset. Continual innovation is seen as a decisive determinant of economic and social development, accompanied by a restructuring of work processes and organisation. In this process the generation, diffusion and utilisation of knowledge has become a core characteristic of firms and economic activity as a whole. These discourses on the emerging knowledge society describe – beyond any doubt – important tendencies of economic and social development. We share the view that knowledge is an increasingly important resource, but we dispute much of the conventional wisdom about how the knowledge economy is structured, and its implications for economic trends and hence policy measures.

On the one hand, the knowledge economy is usually identified with a very small number of research-based or science-based activities, especially information and communications technologies (ICT), and biotechnology. On the other hand, it is often argued that as a consequence of increased knowledge intensity the economies of industrialised countries in Europe and elsewhere are going through at least two great changes (Carson, 1998):

- A significant element of industrial production is moving from its traditional sites to developing countries. The classic example is the exodus of textiles from the rich world over the past three decades. This applies particularly to labour-intensive 'mature' industries: quite soon, it is argued, many big western firms in such industries will have more employees and even customers in developing countries than in developed ones.
- The second change is that, in many industrialised countries, the balance of economic activity is swinging from manufacturing to services. Even in Germany and Japan, which rebuilt so many factories after 1945, manufacturing's general share of jobs of the whole economy is declining very fast, in favour of high tech manufacturing and services.

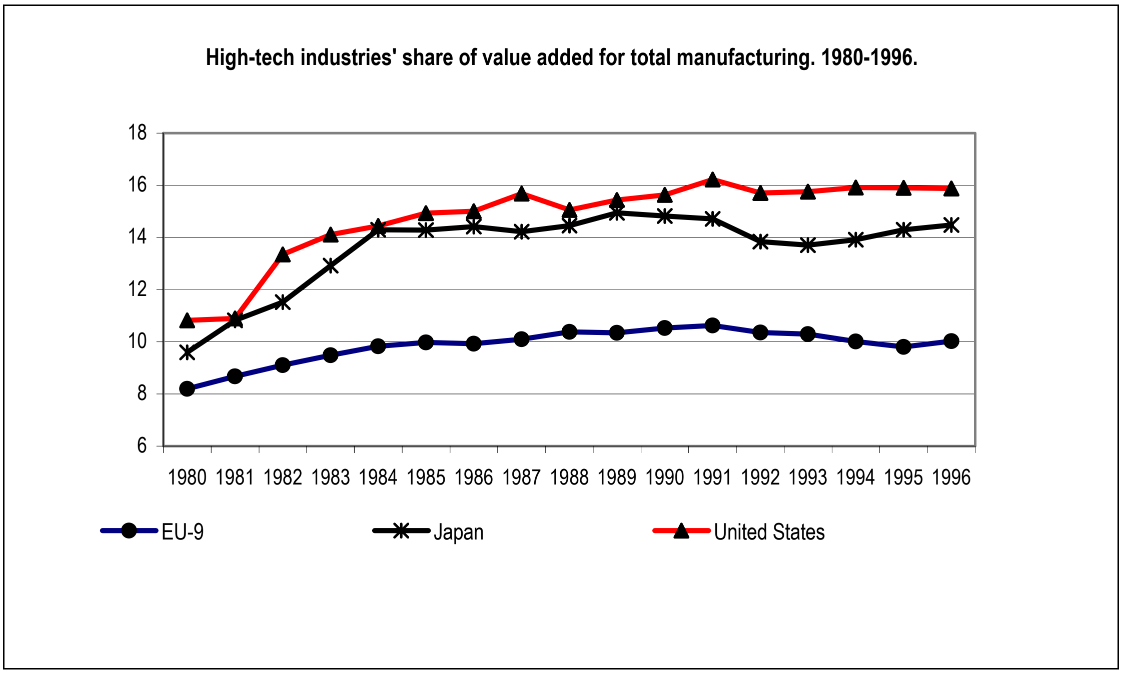
Particularly in Western countries, these alleged trends have caused a debate about an ongoing process of "de-industrialisation" with origin in the 1970s already (cf. Fröbel et al., 1977). By the end of the 1980s, many American and European experts had come to believe that their countries' industries were being "hollowed out" as many basic activities moved to other areas (see especially Dertouzos et al., 1989). At its most extreme, the argument was that only high technology, knowledge intensive activities would survive in the rich countries. But all in all, we would argue, it has not been like that. A change is happening, but it is not simply a destructive change. Rather the industrial sectors of many countries are reorganising themselves in a new economic environment. The result is that many allegedly threatened mature or traditional or low-tech industries are not only still located in their former home countries, but they are also very competitive and successful on world markets.

It is true that the main feature of the current change process is intensified innovation activities of many companies, based on the growing importance and utilisation of knowledge and knowledge work. This change has important implications for corporate strategies and behaviour (see Lazonick 2004, forthcoming, for an account of this). To mobilise knowledge and skills, companies have to introduce and finance specific innovation strategies. These strategies are mainly aimed at changing their traditional organisational and personnel structures as well as their conventional styles of utilising technologies. On the level of the corporation, organisational integration towards innovation strategies becomes a key challenge. On the level of work organisation, more indirect forms of co-ordination are necessary alongside the conventional forms of hierarchical control and co-ordination. This increases the importance of the employees' commitment, motivation and initiative, especially in new forms of work organisation. The participative use of information technologies, the greater importance of organisational culture and the increased impact of inter-organisational production networks are also central elements both in changes in industrial organisation and structure.

However these phenomena are by no means specific to high-technology activities. They hold true also for industrial sectors that can be termed "low-tech", producing mature products like furniture, clothing or light bulbs (cf. The Economist, 1998; Maskell, 1998; Palmberg, 2001). In the public discourse on the emerging knowledge society there is a firm belief that the high-potential and growth sectors are to be found among the industrial sectors that are engaged in new activities, innovative technologies and intensive research and development. The dominant view, in other words, is that such "high-tech" industries hold the key to the future. Such industries are identified with knowledge-intensive sectors, whereas the LMT sectors are usually regarded as based on low levels of knowledge, without a real future in many industrialised countries. Only the high-tech sectors offer prospects for development, and therefore, so the argument continues, it makes sense that economic and science-technology policymakers should favour them.

This argument simply overlooks a key fact: that in all industrialised countries there is a large sector of LMT industries, in manufacturing as well as in service sectors. This holds true for the industrialised countries of Western Europe and as well as for the transition economies of Middle and Eastern Europe with their basis of traditional and mature industries. The empirical evidence is strong and the facts are surprising. Between 90 and 97 percent of GDP in EU countries is accounted for by activities which are classified as non-high tech according to OECD classification routines (cf. OECD, 1999). Figure 1 shows the share of high-tech industries in manufacturing value-added for the Triad from 1980 to 1996 (time period and coverage reflect data availability, but there seem to be no significant changes if we look outside EU-9 or examine the late 1990s). There is clearly rather little structural chagne – the share of high tech industries in manufacturing increases between 1980 and 1984 by between 2 and 4 percentage points for each of the Triad members, after which is remains relatively stable. We should note that these are shares of manufacturing which in each region is less than 25% of GDP and falling throughout the period.

Figure 1



Source: STEP Group from OECD, Industrial Structure database.

Even before the recent industrial downturn led by the ICT industry (classified of course as high tech) many of the fastest growing sectors in the economy were in fact neither R&D intensive nor particularly science-based (Smith, 2003). In international trade, most of the advanced economies are specialized in LMT industries, and this specialization does not affect their growth performance (van Hulst and Olds, 1993). Such sectors generate significant quantities of innovation output, in the sense of sales of new and technologically changed products, and invest significant resources in innovation (Smith 2001).

Let us ask a specific question about what is going on in such industries: why is it that in the face of globalization, in which LMT industries are supposed to migrate to developing economies, the furniture industry survives in Europe? In fact it not only survives, it is one of the most important industries in Europe - it has 65,000 firms, with nearly half a million employees, and an annual growth rate of 4.5 percent (which is faster than the growth of European GNP). Over the 30-year period 1961-1990, furniture was the second-fastest growing product group in OECD manufacturing trade, surpassed only by computers and peripherals. This is despite a significant increase in international competition in furniture, from Mexico, Eastern Europe and Taiwan (Smith 2003).

To some extent, the industry has been reshaped by integration and economies of scale, with firms like IKEA and Habitat reaching mass markets. But European competitiveness has been based on rapid product and process innovation, and the transformation of furniture into a flexible, design-based and knowledge-based production system. Recent research has shown that learning in furniture rests on local innovation systems, characterised by inter-firm collaboration, good quality regional infrastructures, access to high-grade design resources, and highly skilled labour forces. Complex patterns of specialization make this an innovative and growing industry in Europe (see Lorenzen 1998 for a major detailed study).

Borrowing a concept from Kaldor (1985) we may thus argue that the stylised facts of the EU industrial experience indicate that high tech industries are not nearly as important for industrial and economic change as the dominant science and technology discourse assumes. Consequently there are strong arguments for analysing the mechanisms behind industrial and technical change in those parts of the economy in which these mechanisms have been ignored in recent decades. Central among these are LMT activities – they include major activities across the whole of the economic structure, in mining and extraction, in agriculture, in manufacturing, and in both private and public services.

The intention of this paper is to contribute to the study of such industries by reviewing some of the central issues involved in knowledge creation, innovation and change in LMT sectors. So we review knowledge of conceptual and empirical issues related to technologies and industries that are certainly out of fashion, or assumed to disappear – or at least to disappear from industrialised countries – in ongoing structural change driven by globalization.

This paper is not a comprehensive survey of the literature on low-tech industries. Rather we focus on areas we collectively identify as highly relevant for further research and for a deeper understanding of the low-tech world. The paper is structured as follows.

- In section 1 the focus is on the background to the high-tech/low-tech classification – the development of the high-tech race within OECD countries and the work within the OECD related to the high-tech – low-tech dimension.

- Section 2 provides a short discussion of the role of science in industrial and technical change - the present discussion is put into its historical and epistemological context.
- Section 3 explores concepts of knowledge formation which we take to be a broad concept including far more than science. Being by definition non R&D-related, much of the knowledge formation in LMT industries must be found in those activities which fall outside R&D statistics. Tacit knowledge is of relevance here – but in a specific way also codified knowledge. We focus on the specificity of knowledge in low-tech industries and the organisation of its industrial activities. We explore the concept of 'practical knowledge' and the role of intelligent organisation in mobilising the creativity of human capital in relation to LMT industries. We suggest that the use of codified knowledge and scientific results is often intense but non-transparent.
- Section 4 reviews the literature on industrial districts and clusters – many LMT activities are regionally clustered, and this section explores the reasons for and implications of this.
- In the final section our preliminary arguments are recapitulated and the future importance of low-tech industries is underlined.

The appendix includes a bibliography of relevant literature, a list of institutes and scientists conducting research on the low-tech issue as well as information about the authors.

1. The high-tech race

The arguments for focusing on high-tech sectors are actually very old – they date back to the end of the Second World War. For the last four decades industrial researchers and policymakers have intensively discussed international competitiveness in a globalised economy characterised by "international high-technology competition" (Scherer, 1992; van Hulst and Olds, 1993). Both Americans (cf. eg. Dertouzos et al., 1989) and Europeans (cf. eg. Servan-Schreiber, 1967; Sharp, 1983; Freeman and Lundvall, 1988) have contributed to this topic, and several EU-sponsored reports have focused on assessing relative world strengths in technology (cf. eg. Archibugi and Pianta, 1992).

One of the most persistent trends in innovation policy analysis - for more than 25 years - has been the identification of ICT, high technology, and science based industries with the 'knowledge economy.' In recent policy discussion it is rather common to find arguments to the effect that the solution to perceived European economic difficulties lies with a greater emphasis on industries that exemplify high technology, and particular ICT output and use. For example, Fagerberg et al, in a recent study of European growth, argue that:

> … the problems that Europe faces in key areas such as growth, equality and employment are all related to its failure to take sufficient advantage of technological advances, particularly the ICT revolution…science-based industries, particularly those drawing heavily on ICT, have become the main driver of technological change and economic growth since the 1980s (Fagerberg et al., 1999, p. 235).

The policy conclusion from this seems very clear:

> …what Europe has to do is to is to take steps to embed new technologies, especially ICTs, in society. This should bring together regulation, science and technology policy, and employment initiatives (op. cit.).

There are many far less serious expressions of the same views, particularly in policy arguments. In policy arenas it is common for politicians and policy-makers to simply assert that ICT is a technology which stands alone in its impact and implications.

What is the historical and intellectual basis for this focus on high-tech? It may be argued that this interest in science based industrial and technological development – which is what the high-tech discourse is essentially about – originates in four partly related forces:

- the Vannevar Bush model for science and growth;

- the long-run development of corporate capitalism
- the cold war
- perceptions of Triadic competition.

As regards the first, we consider that the Vannevar Bush (1945/1980) report to President Roosevelt on *Science – the Endless Frontie*r laid the ground for a new paradigm which may be called the linear model (Stokes, 1997). The 'linear model' is an ideological construct, a policy-related conception of the process of technological change. It rests on the usually unexamined idea that the knowledge underlying industrial production is defined by principles which are essentially scientific, that is, principles which have in some sense been transferred from scientific research. The process rests on a prior condition, which is an act of search and discovery - via R&D, new scientific or technological principles are elucidated, and the innovation process is seen as one in which the opportunities provided by this discovery are realised. The 'translation' process is basically sequential – from discovery, to engineering development, to new product cereation and then to diffusion or spread.

Bush's report, which foreshadowed the establishment of the National Science Foundation, in effect presented just such a science-based account of competitiveness. Its fundamental claim was that:

> Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science. ... A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill (Bush, 1980, p. 19).

This kind of view about the role of science became quite widespread in documents related to science funding issues. But it is also sometimes expressed by more or less influential science policy-makers, either in the terms seen here, or as a more general statement about the nature of modern technology and its dependence on a science base. For example, Jerome Weisner, Dean of the Science School at MIT, and Presidential Science Advisor during the Kennedy administration, suggested that:

> This is the nature of modern, scientifically-based technology. The first requirement is the existence of a body of scientific knowledge. Then the technologist must have a thorough understanding of the underlying science to use it as the basis for an invention in the solution of a specific problem. Also, more likely than not, he will find that the scientists who first explored the field that he is exploiting left large areas of ignorance which must be filled before his task can be completed. This can only be done by further fundamental research (Weisner, 1965, p. 33).

Although it had only weak support from theory or empirical studies, this linear model gained strong de facto support within parts of academia as well as in policy units. This type of view is by no means a thing of the past, or something which is not present in current policy discussions.

The second force relates to the development of corporate and managerial capitalism, which was observed already by Berle and Means (1932) and Burnham (1941) but attracted new interest in the 1960s (cf. eg. Baran and Sweezy, 1966 and Galbraith, 1967). Alfred Chandler's (1977; 1990) work in recent decades has been seminal. Hand in hand with the growth of big industrial corporations, the innovation processes underwent transformation, as did the analyses of them. This is clear in the writing of Schumpeter which shifted its analytical focus from the "heroic entrepreneur" (Schumpeter, 1911/34) to the R&D department of the big corporations (Schumpeter, 1943/81). The argument was that innovation simultaneously became science-based and institutionalised in the formal R&D departments of large firms. Starting in the German chemical industry in late 19th century this phenomenon of institutionalised and large scale organised innovation rapidly diffused to American firms during the first half of the 20th century (Schmookler, 1957; Freeman, 1974; Mowery and Rosenberg, 1998). Around 1960 innovations were something that had to be *managed* in the R&D units (cf. Burns and Stalker, 1959/61). Despite the fact that many question whether it makes sense to describe either the German or America economies from the late 19th century as "science-based" this connection between large industrial corporate capitalism and R&D-based innovation has become an influential background notion in our time.

The third force was the intensive discussion following after the launch of the Soviet Sputnik in 1957. What Nelson called "orbiting evidence of un American scientific activity" caused a general panic in Western countries about the alleged neglect of science and technology – in policy as well as in the traditional growth models (Nelson in NBER, 1962). This led to a general increase in public-sector support in leading OECD economies in such fields as telecommunications, aerospace, and computing.

The growing rivalry between Western countries during the 60s – after two decades of recovery from the second world war – may be looked upon as a fourth force although it also had a clear relation to the growth of big corporations (cf. eg. Servan-Schreiber, 1967). So-called Triadic competition (Japan, Europe, USA) has since then been a continuous focus of attention by those who believe in the high tech race (cf. Dertouzos et al., 1989; Scherer, 1992; Heiduk and Yamamura, 1990).

Together these forces created the context for the emerging interest within the OECD (cf. OECD, 1971; OECD, 1981) and the European Union (cf. FAST, 1984; EUR, 1994) for the role of science and technology in relation to growth. It may even be argued that this process as a whole constitutes the cultural context for the development of innovation theory or economics of innovation (cf. eg. Freeman, 1974; Dosi et al., 1988; Grupp, 1998).

The details of the intellectual transformation taking place during these decades would require a substantial study. It is obvious, however, that the role of science and technology for growth and development – and thus for innovations – came more into focus in the last four decades of the 20th century than it ever had been before. This process may, to some extent, be the result of a real shift in the locus of knowledge formation in industry, i.e. a "scientification or institutionalisation of technology" as argued by several authors (Freeman, 1974; Mowery and Rosenberg, 1998). It may also be the result in part of a shift of focus of those analysing innovative processes; this will be analysed in the PILOT project.

2. On the role of science in industry and technology

2.1 The interdependence of science, technology and industry

Much of the modern emphasis on high-tech industries rests on the idea of a scientification of the innovation process. In this section we discuss some of the background to this, in terms of the links between science and industry.

The modern focus on the role of science for industrial and technical change and for society as a whole should not obscure the fact that many scholars have approached the topic over the years (cf. eg. Merton, 1938/70; Musson and Robinson, 1969/89; Schmookler, 1950). Whitehead (1925), and the topic therefore has a long history. These writers were clear in the view that the links between scientific discoveries and the world of artefacts are far from simple.

The Bush report, influenced by the success of the Manhattan project, was not so humble in its conclusions. Not only is the concept of basic research – independent of all practical ends – born in the report, it is also assigned the role of pacemaker of technological progress. As we saw above, this was followed by a conclusion on the necessity for nations to establish basic research to obtain a "competitive position in world trade" (Bush, 1980, p. 13). A further review of the basic research concept may lead us too far from our ambitions; but here it is enough to conclude that the linear model which emerged out of this reasoning – although frequently questioned – has become attractive for science and technology policy makers in many countries. The basic science on which innovation allegedly rests has been identified as a public good, with low appropriability, as well as non-rivalry and hence positive externalities, and is thus well suited for publicly financed science policy (cf. Arrow, 1962).

It may be argued that the linear model, as it is deployed in the Bush report, obscures the importance of at least three classes of (partly related) problems: a) the duration problem; b) the independence of engineering and crafts and c) the endogeneity of science.

The duration problem is, quite simply, the fact that there is in many cases a long period between the relevant scientific discoveries and inventions on the one hand and successful innovations on the other. For the inkjet printer, for example, the period between the first reported scientific results on influencing liquid droplets and a commercial printer was as long as 200 years and certainly more than 100 years (Laestadius, 1996). The gap between the discovery of the scientific principles of the laser by Einstein and the first practical applications was about sixty years. Duration periods of decades or even centuries should have implications for the use and abuse of science policy as a means to obtain short- or medium-term industrial and economic goals. The view within modern innovation studies is that duration problems tend to exist because of the complexity of technological knowledge bases - far more than scientific discovery is required for innovation. Production capability involves the integration or articulation of many different modes of knowledge, skills, and competences. These do not develop automatically and may well require the solution of problems that are far more complex than an initial scientific insight.

This leads us to the second problem, the status of engineering knowledge. The problem is whether engineering should be understood as applied science or whether it has an epistemology and procedures of its own, and is thus independent from natural science – though subject to the same natural laws. This problem has attracted researchers on engineering knowledge formation for decades (cf. eg. Layton, 1976 and 1988; Vincenti, 1990; Downey and Lucena, 1995). The independence (parallel) position is supported by results of research by Price (1965 and 1982) and by Brooks (1994) although Narin and Noma (1985) find that science and engineering are more intertwined in the obviously science based biotechnology field. However even in modern technological breakthroughs, like the transistor, it can be shown that the technological paths were far from given by the achievements of science (Gibbons and Johnston, 1982). Several decades ago Rosenberg (1969) made the observation that technological problems solved are just a fraction of those we are capable of handling, thus leaving technological development more or less undetermined by the scientific frontier and more dependent upon imbalances and focusing processes created in the technological system itself.

One conclusion, out of many, which may be drawn from the conjecture of the relative independence of engineering, is that the influence between science and engineering may run in both directions. This topic, here labelled as the endogeneity of science, relates to the fact that throughout history science has developed on the shoulders of instruments and artefacts constructed by craftsmen and engineers (Rosenberg, 1992; Stokes, 1997; Mowery and Rosenberg, 1998; Jardine, 1999; Joerges and Shinn, 2001). Technology – and its artefacts – are not created by science – on the contrary, they often create the foundation for science, and scientists sometimes explain how and why existing things work rather than laying the foundation for inventing them. It is often the case that technologies or production processes generate problems that lead to major scientific breakthroughs – Pasteur's successful solution to the spoilage problems of the Bordeaux wine industry, or Penzias' and Wilsons's solutions to ATT's background noise problems, each involved major scientific breakthroughs.

Questioning science-based innovation models, and the scientification of technology more generally, leads us to a set of empirical problems. These include how innovations in practice occur; what is the role of science, of engineering, of craftsmanship, of design and other forms of knowledge processes, of market reactions, and how do these practices differ between technologies and industries? The Kline-Rosenberg (1986) highly interactive model is one way to handle that problem of complexity, and there are others as well. The Kline-

Rosenberg model in effect sees R&D not as the foundation of innovation, but as the problem-solving activity of last resort – it is what firms do in an innovation project when they cannot solve problems with their existing sets of knowledge and skills. Stepping away from the linear model thus opens up how we can think about innovation, but perhaps more importantly it opens up how we can think about an innovating industry, and from that leads to new territory in thinking about economic growth.

2.2 The OECD taxonomy

Rather than facing the complexity described above, policy analysis has frequently opted for a strategy of simplification. It is common to see the terms 'high-technology' or 'knowledge intensive industries' used in a somewhat loose way, as though in fact they are both meaningful and interchangeable terms. But we ought to remember that the term ‘high technology’ is itself a rather recent invention, and that its meaning is far from clear. A thorough analysis of the internal discussions on the linear model and on the development of the science and technology paradigm that emerged during the 1960s within the OECD falls outside the ambition of this review. However we can note that, to create a common ground for the analyses and policy actions of member countries the organisation began in the early 1960s to collect and publish comparative data on science, technology and industry. The foundation for this activity has for a long time been the *Frascati Manual*, the first edition of which was published in 1963. The present sixth edition (OECD, 2002a) still serves as a common ground for collection of data on R&D.

Starting in 1986 the OECD has also, based mainly on R&D data, classified manufacturing sectors according to R&D intensity (the percentage of total revenue allocated to R&D) (OECD 1986). This led originally to a three-position taxonomy: high-, medium- and low-tech industries. The OECD distinguished between industries in terms of R&D intensities, with those (such as ICT or pharmaceuticals) spending more than four percent of turnover being classified as high-technology, those spending between one and four percent of turnover (such as vehicles or chemicals) being classified as medium-tech, and those spending less than one percent (such as textiles or food) as „low-tech“. A great problem for proponents of this classification is that the high-tech sectors are very small, and this led to the replacement of the three-position model by a four-position model (OECD, 1994):

high-tech industries	R&D/Turnover > 5%
medium high-tech industries	5% > R&D/Turnover > 3%

medium low-tech industries 3% > R&D/Turnover > 0.9%
low-tech industries 0.9% > R&D/Turnover > 0%

In fact the original OECD discussion of this classification was rather careful, and offered many qualifications. Chief among these is that direct R&D is but one indicator of knowledge content. Unfortunately such qualifications were forgotten in practice, and this classification has taken on a life of its own. It is now widely used, both in policy circles and in the press, as a basis for talking about knowledge-intensive as opposed to traditional or non-knowledge-intensive industries. Many countries, and also the EU as a whole, have turned the aggregate R&D/GDP ratio into a quantitative target for science and technology policy as a whole. This is open to two important objections. First, R&D is by no means the only measure of knowledge-creating activities. Second, it ignores the fact that the knowledge that is relevant to an industry may be distributed across many sectors or agents: thus a low-R&D industry may well be a major user of knowledge generated elsewhere. Each of these issued will be discussed in later sections of this paper.

However, it is not clear that this classification helps us, even in a limited analysis of trends. One major problem is that in fact the high-tech sector – as we have noted - is small, and there are therefore real difficulties in arguing that it can possibly drive the growth process. In the OECD, for example, the USA has the largest share of high-tech in manufacturing, but this is only 15.8% of manufacturing output, which in turn is only 18.5% of GDP. So the high-tech sector is less than three percent of GDP. It is hard to see how the combined direct and indirect impacts of such a small component of output could really be a 'driver' of overall economic growth. Could it be that this sector is growing rapidly? Yes it has been growing, but so have other sectors, especially outside manufacturing. In virtually all of the OECD economies the share of high-tech in total manufacturing has risen in the longer term, and this is widely used as an argument for the claim that such industries are central to growth. However this is complicated by the fact that the share of manufacturing in total output has been in long-term decline. So between 1980 and 1995, for example, the high-tech share of US manufacturing increased from 10.5% to 15.8%, while the share of manufacturing in GNP decreased from 21.6% to 18.5%. What this actually implies is that the share of high-tech manufacturing in total GNP rose over fifteen years by well under one percentage point.[1] Despite this, it is not uncommon to see quite sweeping claims made for the high-tech sector, which are not supported by readily available evidence. For example, OECD's *Knowledge Based Economy* claims that 'Output and employment are expanding fastest in high-technology industries, such as computers, electronics and aerospace'. But the OECD's own 'Scoreboard of Indicators' actually shows long-term *negative* growth rates of employment in high-tech manufacturing in eleven of fifteen OECD countries for which data are presented (including the USA, where high-tech employment declined at a faster rate than manufacturing employment generally) (OECD, 1997a, p. 9).

These are essentially first-level problems with any R&D-based classification. To go any further necessitates a more precise analysis of concepts such as science, research (basic as well as applied), development (as D in R&D), invention, innovation etc. As noticed by Rosenberg (1992) and Mowery and Rosenberg (1998) most of the activities in corporate R&D units do not qualify as science as normally defined. This opens up the taxonomy problem which is one of the core questions in the PILOT project and to which we will return in later analyses.

It should be noted however that several of the shortcomings of the present indicators in capturing important aspects of industrial and technical change have been discussed among researchers and policy units during and since the 1990s (cf. Hatzichronoglou, 1997; Kleinknecht and Bain, 1993; OECD, 2002, Smith 2001). This has been an important impulse in the development of direct measures of innovation inputs and outputs, especially focusing on non-R&D inputs, and on new product innovations that can and do occur outside science-based industries.

3. Knowledge formation in industry and technology

3.1 Deficits of knowledge concepts

The high-technology perspective is attractively simple for nations and communities that wish to develop knowledge-based economies. An example is a report of the Irish Science Technology and Innovation Advisory Council (1995): Even though the report – *Making Knowledge Work for Us* – espouses the national system of innovation as a basis for the development of policy, its main focus is on science and advanced technology, to be achieved through increasing R&D. Another example is the annual report of the German Ministry for Education and Research with its exclusive focus on the developmental perspectives of knowledge intensive economic sectors (cf. BMBF, 2002). That in itself

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1 All of the data here is drawn from OECD (1997a).

motivates a more thorough discussion of the high-tech/low-tech concept and its analytical foundation.

Firstly, the indicators of knowledge intensity (i.e. R&D intensity) that are typically used are not robust, in the sense of being consistent across industries and technologies. There is strong variation in the extent to which industries and technologies use R&D to create knowledge. On the one hand knowledge formation is organised differently across technologies and industries – we suggest that whether science (or "research") related activities are more efficient or more growth inducing than other forms of knowledge is an empirical question and should not be postulated a priori. On the other hand there are differences in how industries identify their activities in relation to R&D – it is important to note that R&D statistics focus on the direct R&D expenditure of a firm (whether the expenditure leads to research carried out internally or externally). Non-R&D performing firms may nevertheless be participating in R&D via collective organisations or other indirect forms (such as monitoring university R&D results). As a result, S&T indicators may show a strong variation over industries and technologies as regards the real knowledge intensity as well as its character in a general sense. This issue of data validity also has implications for a correct understanding of industries' and technologies' growth prospects (cf. Laestadius, 1996, 1999; Palmberg, 2001).

Secondly, several successful design oriented firms belong to industries classified as low-tech. The "design" concept is vague – as is the concept "innovation" – and may be in need of a taxonomy of its own. For the moment design is not necessarily classified within the "D" in "R&D" according to the *Frascati Manuals* but there are reasons to believe that a taxonomy starting with design may catch other activities (and still exclude others) in comparison with the activities included in the present formulae. From a practical point of view, the definitions of R&D in the OECD's Frascati Manual, which structure R&D data collection in OECD economies, exclude a wide range of activities that involve the creation or use of new knowledge in innovation.[2] The OECD's *Oslo Manual* explicitly includes

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2 The development definition, on any reasonable interpretation, should include more or less all activities related to innovation. However the Frascati Manual contains a substantial list of exclusions. The most important of these are summarised in Chapter 2.3 and summarised in Table 2.3, which gives guidance on how to divide R&D from non-R&D. Prototypes are basically included in R&D. Both pilot plants and industrial design are only included if 'the primary purpose is R&D'. We would argue that very little pilot or design activity is aimed at R&D, and therefore that most of these central innovation activities are excluded. All improvements in production processes are excluded from R&D. On the other hand, trial production is included 'if it implies full scale testing

design activity and the surveys based on it collect data on design expenditures. Expenditure on design turns out to be an important predictor of innovation performance at firm level.

IKEA, Benetton and H&M are good illustrations of the importance of design. IKEA – belonging to the very low-tech end of OECD classification of industries – has created a capability in design (for manufacturing and for use) and logistics. Benetton and H&M also combine design, marketing and logistics in new forms within the framework of "mature" industries.[3] This innovativeness outside the realm of the S&T paradigm may be illustrated by a recent "airport best-seller" by Kelley and Littman (2001). Although not scholarly, this book invites the reader to a world dominated by creativity and high competence among highly educated innovators in a Silicon Valley based design firm. Most of their design solutions are far from the S&T frontier, yet in fact they are useful, profitable – and low-tech.

Thirdly, the character of the specific knowledge created in several of low-tech industries, and its relevance for innovative capabilities has not been given the attention it deserves. This is important for companies, regions and indeed entire economies. Significant parts of that knowledge may be characterised as predominantly "practical" or "application-oriented", distinct from "theoretical" or "scientific" knowledge, and resembling what Michael Polanyi (1966) has termed "implicit knowledge" in contrast to "explicit knowledge". It may be also argued that the very essence of engineering activity is design oriented. Design can be understood as an intention to create artefacts or technical solutions rather than understanding, and is therefore not part of R&D. We might argue that design and engineering development are focused on the specificity rather than the general (cf. eg. Vincenti, 1990 and Petroski, 1996), but this does not make these activities less technologically or economically significant. The complexity of knowledge formation in technology and industry is thoroughly analysed by Wendy Faulkner (1994; cf. also Faulkner and Senker, 1995) who also provides a typology of knowledge used in innovation, where (experimental) R&D is just one family of knowledge among others (Faulkner, 1994, p. 447). One conclusion that may be drawn from the work of Faulkner is that analysis of knowledge formation in industry and technology has to start in direct empirical research

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and subsequent further design and engineering'. Trouble shooting, patent and licence work, market research, testing, data collection and development related to compliance with standards and regulations are all excluded. Obviously there are difficult boundary prblems for defining R&D. But an important point arising from this is that many innovation-related activities in LMT industries asre likely to be excluded from measured R&D (OECD 2002a, pp.34-50).

3 Indeed, it could be argued that much of the clothing industry, and certainly the designer

capturing the variety across different realms of technology rather than in indirect collection of R&D data.

Fourthly, a recent study on the dynamics and characteristics of firms' relations to external repositories of knowledge (Hales et al., 2001), demonstrates that a distinction between knowledge as furnished by external repositories or 'knowledge bases' and the productive competence underpinning firm-level innovation and behaviour is essential for understanding the 'learning processes' of innovating firms. Rather than 'knowledge intensity', this implies that the relevant driver is 'competence intensity'. Although formulated somewhat differently this perspective is present in several discourses on knowledge formation and creation of firm capabilities. Cohen and Levinthal (1990) for example use the concept "absorptive capacity" and Teece et al. (1997) and Zollo and Winter (2002) use "dynamic capability" to address these issues. The competences and capacities are not necessarily R&D-based, and may involve many non-technological dimensions.

Case studies on competence intensity – facing similar problems of measurement and taxonomy – reveal that the intersection of knowledge intensive and competence intensive industries is far from total. This is still more obvious if the analysis is extended outside the manufacturing sector. For example, even with very conservative criteria normal hospitals show low knowledge intensity (R&D is done elsewhere) and high competence intensity including a very high skilled staff. In the extension of this family of arguments we face the complexity of knowledge formation in networks, in supply chains and in qualified purchasing relations. The dynamics and synergies within these structures and collaborative relations are far from easy to capture and locate to specific actors/industries when using traditional S&T indicators (cf. Coombs et al., 1996; Laestadius, 1996).

Finally, we might question the validity of any knowledge indicators or knowledge analysis that are not sensitive to context conditions. Can we adequately analyse the specific features of innovation and production processes through a more or less isolated approach to "knowledge" or should knowledge be related to its context? Our view is that knowledge formation is highly context specific.[4] This means that if we seek to reveal the specific type and form of knowledge and its relevance to technology and industry, we must focus on its

clothing sector, is based entirely on innovative design.

4 In this sense, knowledge is to be comprehended as a socially determined phenomenon and should not be mixed up with pure data and information (cf. Nonaka, 1994, pp. 15; Willke, 1998, pp.

connection with the action and work context in each case. Such studies have been done on the level of laboratories and breakthroughs of new technological solutions (cf. Latour, 1987). With respect to "traditional" manufacturing, the work by Böhle et al. (1992) should be mentioned. It demonstrates the relevance of the informal side of work organisation and experience-based knowledge to the efficiency of highly standardised and automated production processes. As for the investigation of the seemingly low knowledge-intensive, low-tech work processes, one may come to the conclusion that only the analysis of the whole production and work process makes it possible to draw conclusions on the question whether – and if so – which forms of knowledge are really constitutive of them.

In short, there is a need to reconsider the prevailing understanding of the dynamics of technology and industry. In other words, the black box called knowledge has to be opened and analysed seriously across industries. In the following, some preliminary steps will be taken in this direction focusing on three domains of core importance to the "low-tech discourse".

3.2 Codified knowledge in low-tech industries

We have argued that the most basic mistake in high-tech models is the tendency to identify high-R&D activities with knowledge intensive industries, and hence to see high-R&D activities as bearers of the 'knowledge economy'. We suggest on the contrary that LMT sectors are characterised by complex knowledge bases, involving major engineering, design and production knowledges, and important dimensions of practical knowledge (see section 3.4). At the same time, we argue that the focus on direct performance of R&D in the high-tech/low-tech classification hides the fact that most low-tech industries in fact do use research results and formal or codified scientific knowledges in their products as well as high-tech devices in their production systems.

The key issue in understanding the role of R&D and science in LMT knowledge bases is to recognise that although LMT sectors use formal R&D results and codified knowledge, often in deep and extensive ways, such knowledge use is usually non-transparent. This is because such knowledge tends to be created via interactive processes in other institutional locations, and to flow via mechanisms that are only rarely captured with current indicator methods.

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This refers to modern innovation theory according to which the complexity of the array of agents within an economy, and the complexity of the interactions between them can be regarded as a key element of innovation processes. Systems theories of innovation in particular, which stress the interactions between knowledge-producing agents, point to the idea that economic knowledge is a complex outcome of such interactions. The relevant agents for knowledge production include firms, of course, but also universities, research institutes, government labs, granting councils, consulting companies (particularly engineering consultancies), standards-setting or certification agencies, and in some cases (such as for open source software) user groups. From this perspective knowledge creation and use is a socially collective process. This means firstly that it is misleading to think of knowledge creation in terms of simply the internal R&D performed by a firm (which is what is implied by using R&D intensity indicators as a measure of knowledge intensity). Secondly, it is misleading to think, as argued in some new growth theory literature, of a single 'knowledge-producing sector' that supplies generic knowledge to the rest of the economy. Neither of these conceptions, although immensely popular in both academic and policy discourses, gives us any grasp of the real problems of scientific knowledge creation and use in society because of their failure to incorporate complexity or any of its implications.

From the point of view of firms, the creation and management of knowledge involves system integration. Integration activity is partly a matter of integrating knowledge from different sources, and partly a matter of integrating knowledge with other production-relevant competences. The matter of practical knowledge and related competences has already been discussed. Here we focus on the role of scientific or other codified knowledges in LMT industries.

The main problem here lies in how to conceptualise the knowledge bases of industries, in the context of the complexity of agents sketched above. If we think of knowledge bases in a comprehensive way, then they should include all of the direct and indirect knowledge inputs relevant to the output of a final product: that is, the totality of the knowledge produced by all of the agents contributing to product outcomes. Even a cursory examination of LMT products suggests that these knowledge bases are complex, with many inputs of formal, codified and scientific knowledge results. In wood products, for example, even the first cutting of a wooden log in a sawmill might involve complex pattern recognition technologies using algorithms aimed at the maximisation of yield. In vehicle assembly, high-grade adhesives are normally used, and these are the outcomes of basic R&D in chemistry. In food processing, both production and monitoring require instrumentation technologies based on microbiology, bacteriology, and informatics. Modern synthetic textiles are the results of decades of R&D in the chemical industry. These simple examples can easily be deepened and multiplied, and this is an important research task if we are to gain a full understanding of knowledge complexity. But the general point here is that LMT sectors are not understandable via any distinction between knowledge-intensive and non-knowledge intensive sectors. LMT sectors are intrinsically knowledge intensive in important ways.

This is not simply a matter of passively absorbing knowledge from outside. Many of the arguments concerning generic technologies or ‘general purpose technologies’ simply repeat the logic of the linear model of innovation, in seeing action in one sphere generating the outcomes elsewhere. However complexity of LMT knowledge bases is matched by the complexity of relations among knowledge producing agents. The incentives for the development of high grade inputs to LMT sectors are often internal to the LMT sectors themselves – that is to say, it is performance specifications and desired product attributes generated as aims within LMT sectors that shape the incentives and evolution of the very high-tech sectors that are alleged to ‘ drive’ economic growth. So not only are LMT sectors resting on complex codified and/or scientific knowledge bases, they are generating the depth and complexity of their knowledge bases endogenously.

These inter-agent or inter-industry flows conventionally take two basic forms, ‘embodied’ and ‘disembodied’. Embodied flows involve knowledge incorporated into machinery and equipment. Disembodied flows are sometimes referred to as ‘spillovers’, but this is an excessively abstract term because it implies an automatic process, in which recipient firms are rather passive. In fact accessing disembodied knowledge is an active process, transmitted through scientific and technical literature, consultancy, education systems, and movement of personnel.

The basis of embodied R&D flows is the fact that most research-intensive industries (such as the advanced materials sector, the chemicals sector, or the ICT complex) develop products that are used within other industries. Such products enter as capital or intermediate inputs into the production processes of other firms and industries: that is, as machines and equipment, or as components and materials. When this happens, performance improvements generated in one firm or industry show up as productivity or quality improvements in another. The point here is that technological competition leads rather directly to the inter-industry diffusion of technologies, and therefore to the inter-industry use of the knowledge which is "embodied" in these technologies. The receiving industry is not necessarily just a recipient of such technology: it may actively promote its development (specifying technical and performance functions to producer firms, for example), and must certainly develop the skills and competences to use these advanced knowledge-based technologies (cf. Laestadius, 1998). Most LMT industries are major users of such technologies, and the knowledge underlying them is part of the overall knowledge base of LMT industries.

As examples, consider fishing and fish farming, both of which are apparently low technology sectors in terms of internal R&D. These are a large industries worldwide, with aquaculture growing particularly strongly; this is moreover an important growth sector for developing countries. Examples of embodied flows in fishing include use of new materials and design concepts in ships, satellite communications, global positioning systems, safety systems, sonar technologies (linked to winch, trawl and ship management systems), optical technologies for sorting fish, computer systems for real-time monitoring and weighing of catches, and so on. Within fish farming, these high-technology inputs include pond technologies (based on advanced materials and incorporating complex design knowledges), computer imaging and pattern recognition technologies for monitoring (including 3D measurement systems), nutrition technologies (often based on biotechnology and genetic research), sonars, robotics (in feeding systems), and so on. These examples are not untypical of 'low-technology' sectors – on the contrary, most such sectors can not only be characterised by such advanced inputs, but are as we have noted arguably drivers of change in the sectors that produce such inputs.

We can note that the underlying knowledge for fishing and fish farming mentioned are advanced and research-based. Ship development and management relies on fluid mechanics, hydrodynamics, cybernetic systems, and so on. Sonar systems rely on complex acoustic research. Computer systems and the wide range of IT applications in fisheries rest on computer architectures, and specific programming research and development. Even fishponds rest on wave analysis, CAD/CAM design systems, etc. Within fish-farming the fish themselves can potentially be transgenic (resting ultimately on research in genetics and molecular biology), and feeding and health systems have complex biotechnology and pharmaceutical inputs, and well as foundations in studies of fish behaviour. In other words a wide range of background knowledge, often developed in the university sector, is absorbed in the fishing and fish farming sector.

We would argue that these examples represent a general case in LMT industries, requiring a fundamental reappraisal of our assessment of the relative knowledge intensity of industries. This issue will be an explicit focus in future PILOT studies.

3.3 Codification and the tacit dimension

One of the key elements of modern innovation theory has been also a strong distinction between tacit and codified knowledge in production and innovation. This leads to a temptation to argue that a distinction between high-tech and low-tech industries can rest on the idea that high tech sectors are intensive users of codified knowledge, while low-tech sectors are based on tacit knowledge. As already shown, we would reject this temptation, because there is no total correspondence between low-tech activities and tacit knowledge based activities. There is low-tech outside the domain of tacitness as well as tacitness outside the realm of low-tech. The non-science based character (by definition) of low-tech activities contributes however – when analysing these activities – to a focusing on those elements of creativity, professionalism and skills which are normally connected with tacitness.

The concept itself – usually credited to Polanyi (1958/74 and 1966) – is of recent origin within this domain of social science although it is frequently referred to today, primarily within management theory (cf. eg. Nonaka et al., 2001). Nelson and Winter (1982) make early and path-breaking references to Polanyi's work. With some exceptions, however, discourses related to industry and technology have waited until the new millennium to adopt the tacit dimension (cf. the special issue of *Industrial and Corporate Change*, 2000). The concept is hard to comprehend precisely; since it is frequently defined in connection with the concept of explicit knowledge, and an abundance of synonyms for it are used within the debate in the sociology of knowledge (cf. Ambrosini and Bowman, 2001).[5]

Based on Polanyi's epistemological perspective, tacit knowledge can be defined as follows (cf. Lam, 2000): Firstly, explicit knowledge can be codified, stored and transferred whereas tacit knowledge is intuitive and unarticulated. Knowledge of this type is action-oriented and

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5 Eg. the discourse on artificial intelligence (cf. Dreyfus and Dreyfus, 1986).

has a personal quality that makes it difficult to formalise or communicate. Secondly, explicit knowledge can be generated through logical deduction and acquired by formal study. In contrast, tacit knowledge can only be acquired through practical experience in a specific context. Thirdly, explicit knowledge can be aggregated at a single location, stored in impersonal forms and utilised without the participation of the knowing subject. Tacit knowledge is person- and context-bound. It has a distributive character and cannot be easily aggregated. Polanyi's claim was that the origin of all human knowledge is based on tacit knowledge generated through individual intuition.

The proposition on the existence of a tacit dimension is provocative and has caused an academic discussion which by far extends beyond the intended low-tech focus of this paper. However the debate on tacit knowledge is relevant to our work in number of ways, mainly because it points to variations in the methods of acquiring and using knowledge. For example, it is usually argued that tacit knowledge is acquired at work in an inductive and explorative way – through learning-by-doing. Furthermore, it is supposed to be composed of technical skills and segmented into more or less established work practices, i.e. rules or routines. These work practices and rules are not necessarily person-bound, they are rather work norms accepted collectively by the employees or the community in question. This leads directly to the collective dimension of knowledge, which – due to its co-operative character – must not be ignored when analysing work processes. Collectiveness concerns knowledge which is stored in the rules, procedures, routines and shared norms of a work process as well as the factors which guide the problem-solving activities and patterns of interaction among its members.[6] In this sense, the collective side of knowledge is rather to be found between than within individuals. It can be more or less than the sum of the individuals' knowledge, depending on the mechanisms that translate individual into collective knowledge (cf. Lam, 2000, p. 491). The arguments by Teece and Pisano (1998) are similar and link this to competitiveness: the ability to translate (individual) resources to (firm) capabilities is what constitutes firms' competitiveness. So while we reject the idea that tacitness of knowledge is the only defining characteristic of low-tech activities, it is clear that this concept elations towards important problems in knowledge creation and learning.

6 In this sense, the collective dimension of knowledge refers to the phenomenon which is also called "the collective mind" of organizations (Weick and Roberts, 1993).

3.4 "Practical" knowledge

In order to address such problems, in the context of low-tech industries, and to avoid some of the epistemic problems of the tacitness concept, we may use the concept *practical knowledge*. Here we refer to knowledge acquired through the ongoing process of production, developed and transmitted on the basis of learning-by-doing/using. Such knowledge shows an individual and a collective dimension and it has a highly informal character. Practical knowledge is often not documented or covered completely by work instructions, operation plans and documentation rules. It refers to the informal side of a working process often marked by accepted working methods as well as co-operational and communication patterns, which, however, are not to be found in any official organisation chart.[7] They are accepted, carried out and controlled by the employees involved. Such knowledge is based on collective experience and commonly shared norms on how a working process should take an effective and efficient course. Practitioners tend to know that this may result in clear differences from the officially and formally planned working organisation. Such differences are, nevertheless, absolutely essential for workability and innovation ability.

Practical knowledge can be recorded – unofficially – in personal documents and notes. A widely known example is the operators of computer-controlled machine tools who operate machines by means of unofficial programs which are often unofficially modified. This modification of the programs allows a fine tuning of the operations so that the production process might be much more efficient than if it was run with the official programs.

Practical knowledge is also marked by the fact that it cannot be clearly separated from codified and theoretical knowledge. A number of studies on the course of innovation processes in companies have shown that practical knowledge is always marked by double openness. Bearers of practical knowledge often seem able to adapt and to use knowledge acquired scientifically and systematically in order to cope with specific work problems.[8] Practical knowledge is often the precondition for systematic work rules or engineering and technological findings, prototypes and other products. In other words, practical knowledge

7 In contrast to the formal side of an organization as the planned and officially defined rules system of an organization. It is a generally known fact that the functionality of an organization is based on the interplay of both the formal and the informal side (cf. Mayntz, 1966).

8 This has been instructively shown by investigation results of very different social-science disciplines such as innovation economics (cf. Nelson and Winter, 1982; Faulkner and Senker, 1995), sociology of technology (cf. Asdonk et al., 1991) and sociology of knowledge (Nonaka, 1994;

is in reality closely connected with codified knowledge. In this sense, practical knowledge shows high potential for development with its bearers proving to be very capable of learning. Thus, the above-mentioned modification of NC programs is based on the competent and experience-based adaptation of a given codified knowledge in the form of the programs developed in the programming department and the logical and syntactic rules of a programming language. Another instructive example, described by Laestadius (1995), is the absorption of external R&D results in a company producing anchor cables. It concerns the adjustment of given material parameters to the actual requirements of a forging process whose course is hard to calculate. Obviously, this requires a high degree of practical experience in employees. A third example of this phenomenon is work processes of engineers in construction and development departments. These processes are based on the engineer's skill, i.e experience and "instinctive" feeling, enabling the application of systematically and scientifically acquired knowledge to the relevant problem in order to find solutions (cf. Wengenroth, 1999).

However, practical knowledge can also pass into officially codified knowledge by being recorded in technical documentation and databases. So, the content of the foreman's "black book" can turn into official work instructions and documentation; the operator informs the planning department about modifications, and they are added to the next official program for the computerised machine tools and stored in the database for these programs. In other words, these are processes of knowledge conversion between practical and theoretical knowledge – this appears to be common practice in many companies. These conversion processes can be considered as a central prerequisite for innovations, since in this way new knowledge is created. This may also be the way for transforming disembodied knowledge into embodied (cf. Laestadius 1998). Nevertheless, these processes are not unproblematic, as shown in particular by Nonaka (1994), and complex requirements often have to be met.[9] Nevertheless, this is a major process of knowledge creation which is unrecorded by available indicators and much innovation analysis, yet of vital importance for understanding the knowledge dimensions of low-tech industries.

In analysing the role of LMT sectors in the knowledge economy, we can start from the hypothesis that in industries with low R&D intensity we will find a type of knowledge which comes very close to the outlined features of practical knowledge in a special way.

Nonaka and Takeuchi, 1995;Willke, 1998).

According to Laestadius (1995), this kind of knowledge proves particularly successful for solutions to technical problems and for intelligent variations of solutions to well-known problems, eg.:

- the ability to handle daily specific product materials such as developing and processing specific steel alloys in order to prolong the life-cycle of, for instance, machines used in agriculture;
- the know-how and the experience needed to guarantee the smooth running and the improvement of complex production plants
- the mastering of processes and logistics in order to improve the processing flexibility and the market position of a company
- the competence for a customer-specific interpretation of mature products such as anchor chains on the basis of often incomplete information and specification, and for adjusting it, at the same time, with flexibility to the required technical procedures.

A characteristic feature of the production processes of significant segments of the LMT sector is its reliance on knowledge that is on the one hand created and reproduced through learning-by-doing as well as using, empirical trial-and-error, and limited systematic training. On the other hand LMT firms are characterised by a certain absorptive capacity, i.e. the ability to integrate and utilise codified and scientifically produced elements of knowledge from different, often external sources. In other words, the LMT knowledge base is complex, deep and systemic.

3.5 On the efficiency of intelligent low-tech organisation

The effective use of practical knowledge requires sophisticated enterprise organisation. In relation to how low-tech companies mobilise their specific practical knowledge, a broad spectrum of reorganisation and innovation strategies have been identified in case studies of German companies (cf. Hirsch-Kreinsen, 2000; Schmierl, 2000). They range from a far-reaching technical-organisational restructuring of the entire production process to partial and gradual steps of reorganising certain functions. The organisation must make it possible to continuously use the practical knowledge available and to develop and adjust it in response to new requirements. For low-tech companies, this often means a break with inherited “Tayloristic” structures characterised by a strictly-defined division of labour, highly repetitive tasks and the use of mostly semi-skilled or even unskilled workers. As

9 See also in detail Nonaka and Takeuchi (1995).

shown by Schmierl (2000) but also Hamngren et al. (1995) advanced reorganisations of industries have led to mobilisation of creativity and knowledge which, in many cases, have contributed to significant productivity increases and higher quality performance.

According to the literature dealing with problems of knowledge management, this requires organisational structures enabling intensive interaction and communication between the employees involved and, consequently, a continuous exchange of knowledge as well as collective learning processes. Cross-functional and self-organising teams, which show a high degree of functional redundancy and low task specification of the employees (cf. Aoki, 1988; Nonaka, 1994; Leonard-Barton, 1995; Nonaka and Takeuchi, 1995), are considered to be one central element of such organisational forms. The argument is that cross-functional teams integrate and synthesise knowledge across different areas of expertise serving as a bridge between the individual and the organisation. Interaction, learning and knowledge diffusion – vertically as well as horizontally – is most efficient if it takes place on team level (Lam, 2000, p. 498). Of course, a lot of additional organisational conditions are necessary, if knowledge mobilisation is to work properly. The consistent integration of the teams into organisational basic structures, ensuring orientation and stability, is central to the existence of a company culture conducive to knowledge.

It may be argued that the reorganisation of industrial work (i.e. knowledge management) in order to mobilise the hitherto hidden competencies in the staff challenges our traditional understanding of the concept "innovation". If routine production is mechanised and (virtually) all employees work creatively, the distinction between innovative and non innovative activities will be blurred.

Referring to the results of the aforementioned case studies (cf. Hamngren et al., 1995; Hirsch-Kreinsen, 2000; Schmierl, 2000) the effective reorganisation strategies of low-tech companies depend heavily on the utilisation of external conditions and supportive factors. Establishing relations with other companies, organisations and institutions is an activity even low-tech industries cannot do without. External collaboration helps in overcoming the limitations of a firm's own resources and know-how in developing new production and innovation potential.

As is the case with a number of branches of industry, vertical co-operation with suppliers and distributors has also been gaining in importance for low-tech manufacturers. In many cases relatively loose and order-dependent connections have been extended and intensified in order to optimise the time for delivery, to reduce storage costs, and, first and foremost, to test and probe the potential for the development of the product mix. In order to make co-operation easier, companies very often set up relations with suppliers in their region, in order to maximise face-to-face collaboration.

However, it may be assumed that co-operation strategies of companies differ between countries with specific industrial cultures and traditions. For example, cases of horizontal co-operation with direct or indirect competitors are rare in Germany. Though such strategies are not ruled out in principle as interviews with management representatives showed (cf. Hirsch-Kreinsen, 2000), compared to eg. The “Third Italy” or the furniture industry in Flanders (cf. Pyke and Sengenberger, 1992; Maskell, 1998) they play a minor role in the actual business. The reasons for such regional differences will be further analysed in the PILOT project (see below section 5).

4. Localised industrial creativity – not necessarily high-tech

The strength of Silicon Valley in maintaining its early dominant position in the global ICT-boom during the 80s and 90s has provided inspiration to analysts and policy makers as regards the dynamics of high tech clusters and science parks (cf. eg. Swann et al., 1998). It should be noticed, however, that the dynamics of localised industries seem to be independent of their R&D intensity. In fact it may be argued that competitive industrial districts to a large extent develop – or at least have developed – around LMT industries and technologies. This is the case in, for example, the furniture industry all over Europe (Lorenzen, 1998; Maskell, 1998; Jacobson and Mottiar, 1999; Mottiar and Jacobson, 2002), Italian knitwear (Solinas, 1982) and ceramic tiles (Porter, 1990, pp. 210-225) as well as the Swedish Gnosjö region which is extremely low-tech and has a population with a relatively low level of education, but is highly entrepreneurial.

The idea that proximity contributes to more rapid development of, and diffusion of, practical knowledge emanates from the work of Marshall (1890). Among the factors Marshall identified as “advantages of localisation” was “hereditary skill”. What Marshall was referring to in this context, was not a genetic inheritance. The reference is, rather, to a situation in which a large number of people lived and worked – using similar, specialised skills – in close proximity. The skills in production of the particular product become so well-known in the area after a generation or two that they become almost common knowledge in that place; "children learn many of them unconsciously." Inventions "and improvements in machinery, in processes and the general organisation of the business" become quickly known and copied. There is a milieu that encourages this diffusion. People meet and, through both business and social interaction, share their knowledge. This is what Krugman (1993) refers to as technological spillovers, "the more or less pure externality that results from knowledge spillovers between nearby firms".

Marshall's ideas have contributed to the theory of industrial agglomeration (Jacobson et al., 2002). This is more than just a group of firms in the same place, or a spatial concentration. What distinguishes an industrial agglomeration from a spatial concentration is the presence of agglomeration economies. These are benefits that a firm derives from the fact that there are other firms located in the same place. They are a subset of what Marshall (1890) described as external economies. Knowledge spillovers are an example of this kind of external economy.

Marshall's work also provided the theoretical basis for the analysis of what has come to be known as "Third Italian industrial districts". Emilia-Romagna in Italy has been a particular focus of attention, because of its ceramic tile, wooden toys, textiles and clothing, and furniture industrial districts, among others. As can be seen from the traditional nature of these products, the innovativeness of the LMT industrial districts is concentrated in their industrial organisation and production processes.

There is a close relationship between the now vast literature on industrial districts – both in the Third Italy and elsewhere – and work on learning and innovation. Systems of innovation theories, for example, attributing a critical role to technological, organisational and institutional learning in the process of innovation, stress that learning is an interactive and socially embedded process (Lundvall, 1992; Fischer, 2001). Industrial districts, in which inter-firm co-operation is facilitated by spatial proximity, provide support for the idea that spatial proximity is important in promoting interactive learning, innovation and the development of competitive advantage. Lorenzen (2002) takes this idea further, providing theoretical arguments for ascribed trust being at the heart of the way in which a kind of shared understanding develops in networks of firms. Some of this can be codified, especially in relation to "hard" information such as business data on revenue and profits. This does not particularly require proximity. In addition, even exchange of "complex, tacit, and 'embodied' information" – though requiring trust, and "frequent face-to-face interactions", and though helped to some extent by proximity – is "not severely inhibited by geographical distance". However, to derive benefit from high levels of social trust, sharing in local culture, being part of a community and their rich social capital, does require close proximity. The "social learning processes that create social codebooks ... are constrained by geography", Lorenzen argues, and "hence 'cultures' arise locally – for example in industrial clusters". All these are highly tacit, the costs of their development appear nowhere (and certainly not under R&D expenditure), and yet they contribute substantially to the innovativeness of what Lorenzen calls industrial clusters. His contribution to the development of theory in this area provides a basis for relating the social and cultural to the economic, in a way particularly relevant to LMT industries.

Organisational proximity is of a non-material and non-market nature (Burmeister and Colletis-Wahl, 1997, p. 235), and it "presupposes the existence of shared knowledge and representations of the environment within which the firm exists" (Hudson, 1999, p. 64). Through interactions in intra-industry relations, co-operation and collective learning processes, organisational proximity creates a capacity to assemble fragmented information, tacit knowledge and other non-material and non-standardised resources. Information originating outside the network is received in a qualitatively better way, due to organisational proximity among the actors. Organisational proximity is viewed as a prerequisite for collective learning processes, and for co-operation among different organisations in the creation of new resources and innovation. While organisational proximity is a necessary condition for creating innovations and resources through processes of collective learning, it is also simultaneously a product of the process of collective learning.

Heanue and Jacobson (2002) provide empirical evidence of organisational proximity in the case of a dispersed network of three firms in the furniture industry in Ireland. They show that these firms share values, meanings, understandings and tacit knowledge and a common set of institutions through which these features are produced. The most important mediating institution in this case was the Irish industrial development agency, Enterprise Ireland. The individual involvement of each of the firms over time in various industry initiatives with Enterprise Ireland not only contributed to the development of a shared "worldview", but it also enabled the firms and institution together to identify suitable partners for the current network.

The empirical focus of this work was a geographically dispersed formal network. In contrast, Dahl and Pedersen (2003) examine the case of regionally clustered informal networks. The theoretical context of their work is the recent importance attached to the role of informal networks in the development of regional clusters. In particular, informal contact between employees in different firms is argued to be one of the main carriers of knowledge between firms in a cluster. They empirically examine the role of informal contacts in a specific cluster. The analysis, based on a questionnaire sent to a sample of engineers in a regional cluster of wireless communication firms in Northern Denmark, shows that the engineers acquire and share valuable knowledge through informal networks. The authors argue that this shows that informal contacts are important channels of knowledge diffusion. Again it must be emphasised that firms gaining from this diffusion of knowledge do so without any specific R&D effort; in this case the firm gains without any explicit effort at all. Clustering and knowledge exchange of these types appear to be a pervasive feature of LMT industries (Isaksen 1998), and it is this that links the innovation and growth potential of LMT industries to important regional issues in Europe.

5. The future of low-tech sectors

To summarise the preliminary arguments: it appears that the intelligent and successful production of low-tech products presupposes both a specific practical knowledge available to companies, and the indirect use of complex knowledge inputs which are often scientific in character. This view accords with the recent revival of the debate in the social sciences, dealing with the growing importance of knowledge-intensive work and the need for organisations to learn and to develop know-how. These phenomena are generally regarded as characteristics of an emerging knowledge-oriented society. As emphasised at the beginning of this paper, these ideas reflect important tendencies of social development. However the activities of several LMT companies without any doubt fit into this perspective – not only do such enterprises make intensive use of the knowledge available to them; they also develop it, restructure their organisations accordingly, innovate and grow.

This means that knowledge and knowledge-based innovation strategies cannot be regarded as features of expanding and new sectors, such as professional services, ICT/software or biotech. Without a doubt, these sectors must be regarded as markedly knowledge-based, since they are immediately dependent on the use of explicit knowledge. But as the findings presented here suggest, phenomena relevant to the debate may also be found when one studies other types of knowledge in industrial core industries – industries that from the point of view of an emerging knowledge-based society may seem outdated and far from future-oriented. Such sectors are not marked by gradual erosion – instead they are repositioning themselves in the context of socio-economic change. In spite of globalisation and growing competition, prospects are good in markets for mature products. Partly this is because the specific practical knowledge low-tech companies are provided cannot easily be used by potential competitors. For this knowledge, as mentioned above, can be deeply embedded in the social system of a company and its local environment, which makes it hardly transferable and accessible to competitors (cf. Maskell, 1998). This applies – paradoxically – to standardised products which can considered to be easy to imitate. But such products are often design-intensive, and have major potential for technological upgrading via the use of complex (often scientific) knowledge inputs.

These arguments lead to a specific understanding of the restructuring of the economic landscape of Europe at the beginning of the 21st century. This change does not appear as a wholesale structural replacement of "old" sectors with "new" ones, or as substitution of "old" technologies with "new" ones. It evolves as a restructuring of sectoral and technological systems, transformed more from within than from without. This change process is not dominated by industrial activities where competitive advantage, capability formation and economic change are constituted by frontline technological knowledge. Rather, it is dominated by what are often wrongly termed low- and medium-tech industries. There are many who argue that, since high-tech industries and "knowledge-intensive" industries are one and the same, the economic health of Europe depends simply on the capacity to create and nurture so-called "high-technology" industries. These industries, particularly the information technology and telecommunications (ICT) cluster, are regarded as the bearers of growth, employment and trade success in the future. The policy conclusion tends to be that innovation policy, technology policy and, indeed, economic policy more generally ought to be focussed primarily on the creation of ICT industries.

From the perspective of this paper this type of analysis, and the analytical and policy conclusions that result, are deeply flawed. The concepts and categories used to describe allegedly high-tech, knowledge-intensive industries are seriously oversimplified, lacking empirical support, and conceptually naïve. Rather, we claim that:

- The innovation systems of Europe and indeed of most industrialised countries are strongly influenced by low-tech industries.

- The products of these industries are often growing rapidly and in surprising ways, as a consequence of quality improvements and technological upgrading
- The knowledge bases of these industries are deep, complex and systemic. They are intensive creators and users of practical knowledge and high-grade design skills. They use engineering and scientific knowledge and are closely integrated with the science and technology infrastructure. The mere fact that they do not do much internal R&D says nothing at all about knowledge intensity or their contribution to the knowledge economy.
- They are very often embedded in specific regional structures and are part of regional company networks that differ from country to country and are part of specific national and regional innovation systems.

Furthermore, the involvement of low-tech products and companies is frequently a core precondition both for the innovativeness of value chains – or production systems – and for the design, fabrication and use of a range of high-tech products. Collaboration and networking between companies of different industries at regional, national, as well as transnational levels, are increasingly becoming important determinants of the innovativeness and competitiveness of individual companies. These value chains, *filières* or clusters include low-tech companies not just as tiered participants in supply chains or as more-or-less passive receptors of technologically advanced machinery and equipment developed independently of user specifications. On the contrary, the dynamics and efficiency of value chains may be crucially dependent on the reliability and effectiveness, the capabilities and specific knowledge of their low-tech partners and on their integration into innovation processes in other firms in the cluster, whether low-tech or high-tech. It has to be emphasised that the focus on low-tech firms as parts of wider value chains implies an immediate inclusion of service functions, whether supplied by independently organised service firms, as secondary industrial activities of other firms or through intra-firm production of ancillary services.

This focus on the contribution of low-tech industries for the innovativeness for industry in general is extremely important in a policy perspective, both national and regional innovation policies and for developing a proper foundation for the overall growth and performance possibilities of the European economy. The development of the low-tech sectors is of great importance for both 'old' industrialised and more recent 'high-tech' economic countries and regions. Following the arguments above, the high-tech prospects for many economies are based on the presence and dynamic interaction of reliable „low-tech“ functions and processes. This holds particularly true for value chains which have an increasingly global character and can be regarded as one of the driving forces of the economic development. This aspect is of outstanding importance for the future development of the Central European countries, since many low-tech processes are located there and they are more and more integrated into the internationalised value chains. But we are confident in asserting that the development of Europe as a whole will in future years be based largely on the competitive and innovative capabilities of the LMT industries discussed here.

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Annex 1: Additional low-tech related literature

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Annex 2: Some sites of research on low-tech industries: institutions and researchers

Chalmers University of Technology Dept. of Industrial Dynamics – Gothenburg, Sweden
Keith Smith
www.mot.chalmers.se

Copenhagen Business School (CBS) – Copenhagen, Denmark
Peer Hull Kristensen; Mark Lorenzen, Peter Maskell
www.cbs.dk

Dublin City University Business School – Dublin, Ireland
David Jacobson, Kevin Heaneau
http://webpages.dcu.ie/~jacobsd/

Finnish Forest Research Institute (METLA), Vantaa Research Centre – Helsinki, Finland
Ashley Selby
www.metla.fi

Institute for Labour Foundation (IpL) – Bologna, Italy
Francesco Garibaldo, Andrea Bardi
www.ipielle.emr.it/ita/index.html

Institute for Social Research, e.V. (ISF Munich) – Munich, Germany
Klaus Schmierl, Birgit Knoblach
www.isf-muenchen.de

Royal Institute of Technology (KTH) – Stockholm, Sweden
Staffan Laestadius, Linda Gustavsson
www.indek.kth.se

Stiftelsen Studies in Technology, Innovation and Economic Policy (STEP) – Oslo, Norway
Johan Hauknes, Trond Einar Pedersen
www.step.no

Technology Research Centre of Finland (VTT) – Espoo, Finland
Jukka Hyvönen, Marja Nissinen, Torsti Loikanen
www.vtt.fi/ttr/indexe.htm

The Research Institute of the Finnish Economy (ETLA) – Helsinki, Finland
Christopher Palmberg, Hannu Hernesniemi
www.etla.fi/english/main

University of Dortmund; Chair of Economic & Industrial Sociology – Dortmund, Germany
Hartmut Hirsch-Kreinsen, Gerd Bender
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